MIXING CHARACTERISTICS OF A FREE JET BOUNDARY WITH CONSIDERATION OF INITIAL BOUNDARY LAYER CONFIGURATION

BY

ALAN JESSE CHAPMAN

B.S. in M.E., The Rice Institute, 1945

M.S., University of Colorado, 1949

R. UNIV.
BIBLIOTHEEK
LEIDEN

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN MECHANICAL ENGINEERING IN THE GRADUATE COLLEGE OF THE UNIVERSITY OF ILLINOIS, 1953

URBANA, ILLINOIS

MIXING CHARACTERISTICS OF A FREE JET BOUNDARY WITH CONSIDERATION OF INITIAL BOUNDARY LAYER CONFIGURATION

BY

ALAN JESSE CHAPMAN

B.S. in M.E., The Rice Institute, 1945

M.S., University of Colorado, 1949

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN MECHANICAL ENGINEERING IN THE GRADUATE COLLEGE OF THE UNIVERSITY OF ILLINOIS, 1953

URBANA, ILLINOIS

MIXING CHARACTERISTICS OF A FREE JET BOUNDARY WITH CONSIDERATION OF INITIAL BOUNDARY LAYER CONFIGURATION

An analytical treatment is developed for the free jet boundary problem including the effects of the initial boundary layer configuration for mixing regions in which a constant pressure equal to the pressure of the ambient stationary fluid can be expected. The equation of motion applied to the free jet boundary is linearized by utilization of the method of small perturbations of S. I. Pai. This reduces the problem to the solution of a linear parabolic differential equation of second order. The equation is of the type of the heat conduction equation with a constant coefficient. The velocity distribution in the approaching boundary layer just upstream of the free jet enters the problem as the initial condition. The constant coefficient of the differential equation involves the fluid viscosity. In the case of laminar flow the kinematic viscosity appears in the coefficient. In the case of turbulent flow, the apparent kinematic viscosity is represented by the relation proposed by S. I. Pai, involving two empirical quantities, and one of these empirical quantities appears in the constant coefficient of the differential equation.

The solution of the problem, i.e. the velocity profiles within the mixing region, appears as the function of three parameters, one involving the coordinates of a point within the mixing region, one involving the initial boundary layer thickness, and one involving the shape of the initial boundary layer velocity profile expressed by the exponent of a power law. This is an extension of the one parameter theories of Tollmien and Görtler in which the initial boundary layer is not accounted for. The solutions of the present theory approach asymptotically the solutions of Tollmien and Görtler as the effects of the initial boundary layer diminish.

While analytical results which involve no empirical quantities are obtained for the laminar case, emphasis is placed on the case of turbulent flow. In this case the assumed relation for the apparent kinematic viscosity introduces two empirical quantities requiring experimental determination. The theoretical velocity profiles within the mixing regions are presented graphically for values of the exponent in the initial boundary layer profile power law ranging from one to one-tenth. Tests were conducted, using air as the fluid, to determine the empirical quantities involved in the

turbulent viscosity assumption. The velocities encountered were within the incompressible flow range. Tests were conducted for a variety of initial boundary layer configurations, the exponent in the initial boundary layer profile power law being varied from about one-half to one-ninth. The tests indicate that the theory adequately describes the velocity distributions within the mixing region of a free jet boundary. The values of the empirical quantities were determined for each condition of the initial boundary layer. One of these quantities appears to be constant, for the range of the tests conducted, and leads to the inference of a modified mixing length concept. The other empirical quantity appears to be a function of the initial conditions. Although the tests were conducted only for incompressible flow conditions, this restriction is not inherent to the theory itself.

VITA

Alan Jesse Chapman was born on June 22, 1925 in Los Angeles, California. He received the degree of Bachelor of Science in Mechanical Engineering from the Rice Institute, Houston, Texas in June, 1945. He served in the U.S. Navy from 1943 to 1946. Upon release from the Navy, he returned to the Rice Institute as Instructor of Mechanical Engineering. By attending the University of Colorado during successive summers he received the degree of Master of Science from that school in August, 1949.

He was appointed an Assistant Professor of Mechanical Engineering at the Rice Institute in September, 1950, which position he now holds. Additional study during the summers of 1951 and 1952 was carried out at the University of Illinois. He was then granted a leave of absence by the Rice Institute for the 1952-53 academic year, during which time he has been in residence at the University of Illinois.

He is a member of Tau Beta Pi, Sigma Xi, and is a Registered Professional Engineer in the State of Texas.